MODERN WORLD SERIES

Progress in Science

SIR GERARD THORNTON
SIR EDWARD APPLETON
SIR ALEXANDER TODD
SIR MILES THOMAS
SIR JAMES PATERSON ROSS
LORD MORAN
DR. A. S. PARKES
AIR COMMODORE SIR FRANK WHITTLE
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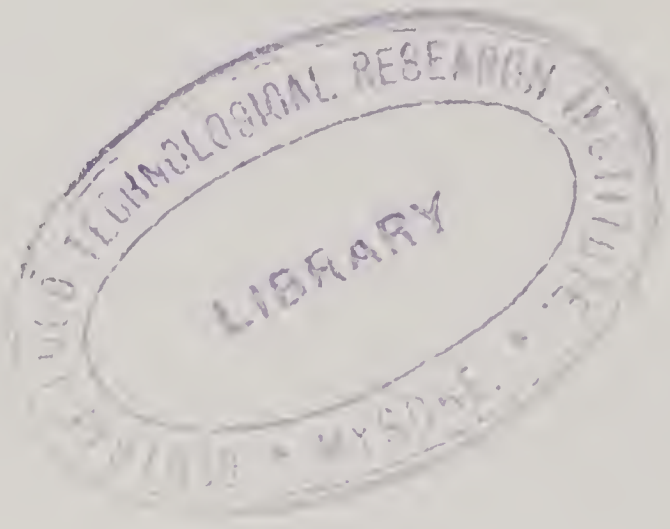

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The Royal Society of London

BY SIR GERARD THORNTON

At the beginning of the 17th century the attitude of philosophers towards natural science was revolutionised by the writings of Francis Bacon. He expounded the experimental method of research and vehemently protested against the blind following of unproven dogmas that was in vogue until then.

Bacon thought that his proposed method should be carried out by a group of men devoting their time to experimental philosophy and working together. In his *New Atlantis* he describes how such a College might be set up.

During the difficult times of the Civil War a number of men interested in natural philosophy and in Bacon's experimental method began to meet weekly in various places, each paying a contribution to carry the cost of their experiments. This body came to be known as the Invisible College. After the Restoration their meetings continued in London at Gresham College, one of their former meeting places and, on 28th November, 1660, it was decided to establish a College having a formal constitution.

Shortly after this, King Charles II, a man of considerable intellectual ability, gave encouragement to this body, which became known as the Royal Society. Under this title, it was given a Royal Charter of Incorporation in 1662, amplified by later Charters, one in 1663, in which the King described himself as Founder and Patron of the Society, and a third in 1669.

The King also gave the Society two of its most treasured possessions: a mace, still placed before the President at meetings of the Society and of its Council, and a folio volume which bears the signatures not only of successive Sovereigns as Patrons, but of the Fellows from the inauguration of the Society till the present day.

The rapid development of natural science that began in the second half of the 17th century owed much to the Fellows of the Royal Society. Robert Boyle and Robert Hooke, whose names are

immortalised in laws of nature, were leading figures at its meetings.

In 1671, the Society's greatest Fellow, Isaac Newton, was elected to the Society at the age of 29 and became President in 1703. The manuscript of Newton's *Principia* in which he expounds the law of gravity, is the Society's most precious scientific treasure. Newton himself was indifferent as to the publication of the *Principia*, and it was due to the successful persuasion of the astronomer and physicist Edmund Halley that this great work was at last published.

During the 18th century the Society benefited much from the generosity of King George III, who gave it premises in Somerset House, London, since when it has occupied premises provided by the Crown. We have resided at Burlington House, Piccadilly, London, since 1857.

The voyages of Captain James Cook were carried out under the scientific direction of the Society. The War of Independence was in progress at this time and the Society gratefully remembers that Benjamin Franklin, who had been elected a Fellow in 1756, saw to it that Cook's expedition remained unmolested by the American Navy.

Sir Joseph Banks, a distinguished botanist, accompanied Cook on his voyages. Banks later held the office of President from 1778 until 1820. During this period Fellows carried out work that is now classical, including that of Henry Cavendish and James Watt on the composition of water, and Herschel, who discovered the planet Uranus, in astronomy.

It is not possible to list here the distinguished Fellows who have contributed to the great development of science since the opening of the 19th century.

Many of them have opened new chapters in the history of science and made discoveries whose effects in the improvement of human welfare cannot be measured. A few of these were Humphry Davy, John Dalton, Michael Faraday, Clerk Maxwell, Lord Kelvin, J. J. Thomson, Ernest Rutherford, Charles Darwin and Joseph Lister.

The number of Fellows remained between 100 and 200 during

the 17th century, but thereafter rose steadily until in 1847 there were 764. Then stricter rules on qualifications for election were introduced and the number of Fellows elected each year was reduced to 15, a number which has since been raised to 25.

There are three main categories of Fellowship today under the Patronage of Queen Elizabeth II. The first is that of Royal Fellows, which at present comprises Queen Elizabeth the Queen Mother, and three Royal dukes including the Duke of Edinburgh, whose personal and active interest in science and in the Royal Society we greatly appreciate. The second category is that of Foreign Members, of whom there are now 65 distinguished scientists from many lands. The third category, that of Fellows who must be citizens of the British Commonwealth or of the Irish Republic, constitute the main element of the Fellowship. There are now 597 of these, of whom about 72 reside overseas.

An important activity of the Royal Society is the holding of scientific meetings and the publication of research work. The weekly scientific meetings include those at which original papers are read, special discussion meetings and lectures such as those describing the work of research institutes. There are also several lectures given at the Society as a result of endowments. The oldest of these are the Croonian and the Bakerian, which originated in 1701 and 1775 respectively, and the most recent, the Leeuwenhoek, established in honour of the Dutch naturalist of this name who first observed and described bacteria and who communicated many of his observations to the Royal Society.

The publication of scientific work by the Society began in 1665 when Henry Oldenburg, one of the original Secretaries of the Society, started the *Philosophical Transactions of the Royal Society*, now the world's senior scientific journal. In 1832 a second journal, the *Proceedings*, began. The Society also publishes a Year Book, a most useful work of reference on the Society and its current work, a volume that contains the obituary notices of past Fellows which is a valuable contribution to the history of science, and a journal, *Notes and Records of the Royal Society*, that appears twice yearly. A library, started in the Society's early years, is also maintained and now contains some 150,000 volumes.

The Royal Society has funds, mainly derived from donations and bequests, for the direct support of scientific research. These now have a capital of about £1,200,000; with their help the Society finances a research Professorship and some 25 other research appointments.

In addition to its own research funds the Royal Society also administers Parliamentary grants for the assistance of research, scientific publications and of international research and congresses. Indeed, much of the time and activity of the Society and of its Fellows is devoted to the carrying out of its public responsibilities. It took a leading part in establishing Britain's National Physical Laboratory and still controls its scientific policy. It has become the practice that the President of the Royal Society be consulted in making appointments to the Research Council of Britain's Department of Scientific and Industrial Research and to the Agricultural and Medical Research Councils, and Fellows serve in all these bodies and on the Advisory Council on Scientific Policy.

In addition, Fellows of the Society assist by advising the Government on many scientific matters and are appointed to about 100 governing bodies and committees of leading universities, colleges, schools and research institutes.

In such ways the Royal Society, though it possesses no research institutes of its own, does very much through its Fellows to influence the course of development of science in the United Kingdom.

The co-operation between scientists of different nations is one of the most hopeful developments in the international field, with the promise that it holds of more friendly relations between them. Such co-operation is indeed necessary for the development of some fields of science such as meteorology, geophysics and oceanography. This is exemplified by the International Geophysical Year, the most successful example of international co-operation in science so far achieved. In this enterprise the Royal Society took a leading part.

The full title of the Society is 'The Royal Society of London for the Promotion of Natural Knowledge'. This title defines one of

its important characteristics. It is concerned only with natural knowledge and not, like many National Academies, with the humanities.

A second important character is that the Royal Society is a private and independent scientific society. This private Society owes its influence to its prestige. It has achieved and maintains this prestige by its insistence on upholding the highest scientific merit, not only in its awards and in choosing the recipients of its research grants, but especially in the selection of those persons that it deems worthy of election to its Fellowship.

The British Attitude to Science

BY SIR EDWARD APPLETON

The International Geophysical Year 1957–58 provided a clear illustration to the world of the way science is an international activity. For, during that intensive period of scientific observation, the world has ignored political boundaries in studying itself. To the scientist, then, there is no such thing as national science. But there is, by contrast, such a thing as a national attitude towards science. And, undoubtedly, our British attitude towards science has affected the way we in the United Kingdom have worked at it in the past, and so has influenced our particular achievements in it.

We always picture the age of modern science in Britain as beginning with the foundation of our Royal Society, which celebrated its tercentenary in 1960. The objectives of the Society were stated in its Charter as being twofold: the promotion of 'the science of natural things and of the useful arts'.

In modern phraseology we would say that this meant both pure science and applied science; though, in fact, as the published records of the Society clearly show, the first interest of the Fellows of the Royal Society has always been 'the science of natural things'—or science for its own sake.

They have not given anything like the same attention to the application of science—the applications of science to the arts of life. We must remember here that the conversion of Britain to a manufacturing nation—the Industrial Revolution as it is termed—owed less to science than to a number of outstanding inventions made by men actually working in various industries.

Scientific research, which had begun in Britain as an amateur activity, remained predominantly the activity of individuals. Only recently—within, say, the last 50 years—have we started to organise professional teams of scientists to work on problems of industrial and military importance. Our early achievements have therefore been largely in the field of pure science, where the freedom of the

individual to choose a problem that interests him is so vitally important. It is our individual approach to science that has enabled us to isolate and study distinct problems.

In the same connection I think it is fair to say that we have displayed a happy knack of being the first to get to the bottom of many of them. Take, for example, two modern developments in industry today—the subjects of electronics and nuclear energy. The first word on both subjects was said by two scientists working in Britain, both University Professors who were simply working at problems in pure science which interested them. Sir J. J. Thomson discovered the electron at Cambridge, while Lord Rutherford discovered the atomic nucleus at Manchester.

One can mention other British names—for example, in the biological sciences—names of men who, working as individuals, have made basic discoveries which have proved the starting points of great advances in their respective fields. I need only mention here such names as William Harvey, who discovered the circulation of the blood; Charles Darwin and his theory of evolution; and Sir Gowland Hopkins, the discoverer of vitamins.

You will see, then, that the start of any new development in science is usually the work of a single person. An adventure takes place in one man's mind, as a result of which either a scientific theory emerges or a new experimental discovery is made. It is knowing how or where to start that matters. If the start has opened up a fruitful field—fruitful in practical consequences, that is—we usually want a team of applied scientists to follow it up and reap all its benefits.

Take a more modern instance than those I have mentioned, that of penicillin. It was discovered by Sir Alexander Fleming—one man. Its therapeutic properties were first fully demonstrated by Sir Howard Florey and Dr. Chain—two men. Nowadays there must be many thousands of people working in this important branch of medicine.

Now, although I am claiming that British scientists have been responsible for many of the basic discoveries in natural science, it cannot be claimed that, in the past, Britain has been as alert as some other countries in following up the useful applications of

those discoveries. Indeed there are notable instances where a British basic discovery has been chiefly developed elsewhere. The discovery of an aniline dye, by W. H. Perkins, in London, was, for example, the starting point of the growth of the great German dyestuffs industry, in the days before World War I, there being no corresponding development in Britain. It seems, somehow, to have needed national emergencies really to awaken us to the economic and military importance of scientific applications.

It was our experience in the 1914–18 War, when we had to start manufacturing things we had previously imported from abroad, which led the British Government to found the Department of Scientific and Industrial Research, an organisation which has not only done applied research itself, but has also fostered the growth of co-operative Research Associations in industry. This Department, together with corresponding organisations for agriculture and medicine, caters for research over a wide front in the civil field. Their importance is recognised by the fact that they are under a senior Minister of the Crown, the Lord President of the Council, as Minister for Science.

However, it was just before, and during, World War II that Britain most effectively demonstrated that we could do team work in applied science, as well as individual work in pure science, when the need arises. It was the threat of enemy bombing which prompted us to take the world lead in the development of radar; and it was a British invention, the cavity magnetron, which has transformed that subject in the realm of accurate navigation by sea and air. Further evidence of our ability to do team work in applied science is demonstrated by the co-operation of government and industrial scientists in harnessing nuclear power for the generation of electricity to serve our homes and industries.

So the situation is this—in the past we have tended as a nation to concentrate on pure science, in which we have a proud record of achievement. But we have now shown our friends, as well as ourselves, that we can be just as successful in harnessing nature as in understanding it.

The State and Science

BY SIR ALEXANDER TODD

The power of a nation has always depended on its level of technological progress in the military, agricultural or industrial spheres. But until quite recently, technological advance depended on the chance appearance of inventions which could then be applied and developed to particular ends. This was true of the first phase of the industrial revolution in Britain in the early part of the 19th century, but just about 100 years ago a profound change occurred. For the first time, science and the scientific method began to be applied directly to the solution of industrial, military and agricultural problems.

It was this new factor which, gaining impetus over the years, was to lead to the sensational developments of the 20th century in all these fields and to an ever-increasing rate of industrial progress. In these circumstances a country such as Britain, small in area and natural resources, but large in population, must be strong in science if it is to survive and prosper in the modern world.

Science is thus vital to the State, and recent United Kingdom Governments have sought in steadily increasing measure to promote both science and technology. The recent appointment of a Minister of Cabinet rank with full-time responsibility for the promotion of science and technology is a new landmark in the relation between the State and science and underlines the importance now attached to that relationship.

Government participation in science and technology and in their promotion is not without its dangers and requires careful handling. Pure science can only flourish properly in an atmosphere of complete freedom, and the stimulation of technological progress in industry must not stifle free enterprise by subsidising the inefficient.

The relationship between Government and civil science has for these reasons evolved gradually in Britain and has resulted in

a loose complex of organisations and avenues of support. These are now the responsibility of one Minister and are represented, together with independent scientists, on his Advisory Council on Scientific Policy. This is a body which, in addition to its general policy function, is charged by the Government to keep under continuous review and to make appropriate recommendations on the supply of and demand for scientific manpower.

It is on the basis of the Council's forecasts of demand, and those of its predecessor, the Barlow Committee, that the British Government's large programmes for scientific and technical education since World War II have been founded.

Government support for science in the civil sphere is directed through three main channels. First, there is research undertaken in the Government's own research institutions, which are grouped under four Research Councils (the Department of Scientific and Industrial Research, the Medical Research Council, the Agricultural Research Council, and the Nature Conservancy); under the United Kingdom Atomic Energy Authority, and, to a lesser degree, through some other agencies such as the Development Commission, the Royal Observatories, and Departments such as the Post Office.

Secondly, Government grants are made to no fewer than 49 industrial research associations which, between them, cover a very large area of British industry. Thirdly, the Government supports pure research in the universities through the University Grants Committee, both as to capital and recurrent expenditure and through direct grants for special researches administered by the Research Councils and by the Royal Society; in addition, a large programme of post-graduate studentships and fellowships for training in research is administered by the four Research Councils.

The oldest, and largest, of the Research Councils is the Department of Scientific and Industrial Research. This was created more than 40 years ago to promote technological progress in British industry by the conduct and support of scientific research, both pure and applied, and by making known the results to central and local government, to commerce, and to industry.

These ends it seeks to achieve by carrying out research under

its direct control in 14 national research establishments, and by encouraging industries—especially those in which individual units are small—to form Research Associations financed partly by the Government and partly by the firms themselves. The Department also seeks to ensure a steady flow of trained research workers by the award of training grants for post-graduate workers and by supporting research projects in universities, technical colleges and elsewhere.

The growth of the Department was steady rather than spectacular up to the time of the last war. But since then it has enormously increased its activities, and is now in a period of rapid expansion.

The same is true of the other three Research Councils, all of which, in addition to maintaining their own national institutes in various branches of their fields of science and technology, support research in universities and award training grants for young research workers. Some idea of the current rate of expansion can be gathered from the fact that the Research Councils alone now dispose of some £20,000,000 a year for these purposes compared with £10,000,000 in 1951. And their rate of growth continues to increase, in step with increasing facilities and the increased number of scientists being produced by our universities and technical colleges.

In seeking to achieve its goal of doubling our output of scientists (already more than doubled in the previous decade) between 1956 and 1970, the Government is providing capital for university building through the University Grants Committee as rapidly as it can be absorbed—something like £15,000,000 per annum—and is promoting technical college building through the Ministry of Education on roughly the same scale. Hand in hand with these capital grants are correspondingly large increases in grants for recurrent expenditure.

These are impressive advances, particularly when to them one adds the sums spent on research on the peaceful uses of atomic energy, including contributions to such organisations as the European Organisation for Nuclear Research. But they give no grounds for complacency. The need for even greater efforts has

been stressed by many individuals and organisations including the Advisory Council on Scientific Policy.

In the past, British Governments may have been slow to recognise this need, but times have changed and with the appointment of a Minister for Science and the Government's expressed intention of further increasing national support for science, there is good reason to believe that British science will be able to play its full part in the nation's life and, at the same time, add further to its laurels.

Achievements in Research, Industry and Technology

BY SIR MILES THOMAS

In a quiet corner of Cheshire, one of Britain's agricultural counties, a group of men are working on what may provide a clue to the age-old question: how did the universe begin? Through the giant radio telescope at Jodrell Bank, they probe the frontiers of space and time. The events that they witness today actually took place millions of years ago. What they discover may help man to build a picture of how the universe came into being. In between this work, they also keep track on the man-made satellites that circle the earth and rockets that aim at the moon.

This telescope at Jodrell Bank is the world's biggest and best. The men working there are leaders in their field. Without their help, those responsible for satellites and rockets—perhaps more spectacular and more glamorous work—would not be able to obtain complete checks on the results of their activities. The whole world, indeed, would be the poorer without Jodrell Bank—and may well, in the future, regard Jodrell Bank as the originator of solutions to many of science's most basic problems.

But this giant telescope is only one of the aspects in which British science and technology is today leading the world.

In the air, it was Britain who pioneered the great jet airliners that are now in service on international routes. It was the British aircraft industry whose faith in itself, after the tragic history of the earlier Comets, was vindicated by the achievement of the Comet 4, the first jet liner in regular service across the Atlantic. Not only in jets does Britain lead. The turbo-prop Britannia, Viscount and Vanguard airliners are leading the field for that type of aircraft.

And even where the aircraft are not British-made, it is more often than not British-made or designed engines—such as Rolls-Royce and Bristol—that are used to power the aircraft that are being built in other countries.

This progress in the skies and the air is one of the reasons that make me proud of Britain's contribution to the amazing progress that has been achieved since the war. Britain, which pioneered the industrial revolution of the 19th century, now pioneers the atomic age of the 20th. She is in the front rank in the efforts to make life safer and more rewarding for every one of us.

Britain already leads in the use of nuclear fission for peaceful purposes. She was the first to build a full-scale nuclear power station supplying electricity for normal industrial and domestic purposes, and this was done despite the fact that Britain had to begin her nuclear fission research again after the war. Now she is ahead of all her rivals in the commercial applications of nuclear power.

The first atomic power station, at Calder Hall, on the north-west coast, supplied 438,797,000 units of electricity—produced by two reactors only—to Britain's National Grid between April 1957 and March 1958. The third reactor went into operation in March, and a fourth in December of the same year. Other nuclear power stations are now being built in various parts of the country.

In addition, research continues into the possibilities of harnessing the power from nuclear fusion. Other countries, too, are working on similar lines, but Britain is well in the forefront of this research.

Science and industry, research and production are advancing together. In Britain altogether more than £300,000,000 is being spent annually on research and development in science and technology.

In recent years Britain has led the way in giving the world radar and television, and a British company has recently produced what is said to be the most versatile television colour camera yet developed.

British industry gathers more strength each year—especially in the new industries of this exciting century. Our electronics industry has increased five-fold since the war and is now the second largest in the world. Recently, there was held in London an exhibition of electronic computers and other devices, including one that can 'read'.

The plastics industry—with which I am myself connected—has, within a few years, become one of Britain's greatest exporting industries. Of its output of 400,000 tons in 1957, more than 25 per cent was sold to other countries. Developments in British plastics and man-made fibres are followed with close interest throughout the world.

And, apart from what may appear to be the immediate economic aspects of achievement, Britain has scored striking successes in other fields of scientific endeavour. In 1958 the world applauded the achievements of a British car, the Vanwall, in winning the Grand Prix car championships. And, of course, it was a British Commonwealth expedition that recently crossed the Antarctic on land—and a British team that conquered Mount Everest!

The many achievements by British industry and British scientific research, and by the individuals working here—it was a Briton who recently won the Nobel Prize for chemistry—are some small indication of the vitality and energy of the country.

Britain is accepting willingly—and eagerly—the many challenges of the new technological age. We in British industry are alive to the great potentialities of the future. We face that future with determination and high confidence.

Contribution to Surgery

BY SIR JAMES PATERSON ROSS

In Britain, at the beginning of this century, it was often necessary for a patient to travel a long distance, occasionally even to go abroad, to obtain the special skill and experience required for the management of his particular malady. In those days, there were relatively few surgeons capable of undertaking the more extensive and hazardous operations, and they enjoyed a corresponding measure of well-deserved fame and honour.

Today, there are so many highly trained surgeons in the numerous hospitals throughout the country that a patient can be given surgical care which was not even contemplated 50 years ago without having to go far from his home, his relatives, and his familiar friends and surroundings. Indeed, it is only when treatment involves the use of elaborate and costly apparatus that he may have to travel some distance, but not to go abroad, to obtain it. The boon of good surgery within reach of everyone is perhaps the most important of the benefits of the National Health Service.

During this same period of time the means of international communication through travel, correspondence and literature have been so greatly facilitated that it is often difficult to trace the exact origin of the idea which initiated a new technique. In making this review of surgical progress there is no need to argue about priorities, yet it will be clear that many of the recent advances in surgery have originated in Britain.

It seems natural to consider first the correction of errors of development, malformations present at birth, which are now the concern not only of the plastic surgeon but also of an increasing number of specialists who devote themselves to the surgery of infancy and childhood. The gullet or the intestine may fail to canalize, but operation now saves the lives of many an infant thus afflicted who would formerly have died shortly after birth.

Every schoolboy now knows about holes in the heart which

can be repaired when the circulation is temporarily taken over by a 'heart-lung machine', one pattern of which has been developed at the Post-graduate Medical School of London and has been used with success and satisfaction in several hospitals at home and abroad. Apart from these spectacular examples of surgery for congenital malformations, the investigation of maldevelopment of the lymphatic vessels by X-rays (lymphangiography), which also originated in London, has established the rational basis for the operative treatment of elephantiasis of the legs (lymphoedema).

A serious problem in its magnitude and urgency which faces communities all over the world is that of accident services to cope with the alarming number of casualties on the roads, in industry and in people's homes. It is primarily a matter of organisation, and was well tackled during the second world war by the Emergency Medical Service, which might be used as a pattern for casualty services in time of peace also. Britain has reason to be proud of her blood transfusion service, and of the researches into blood grouping, and into disorders such as haemophilia which have been elucidated by a team of scientists at Oxford.

To an Englishman we owe antiseptic surgery, and it was the researches of Fleming in London and Florey and Chain in Oxford that gave us penicillin, the first of the antibiotics. Curiously enough, it is British bacteriologists also who have been most insistent in warning clinicians about the ill effects of the misuse of antibiotics. These have played a leading part in the investigation and prevention of hospital infection, the prevalence of which in all parts of the world in recent years must be associated with the phenomenon of bacterial resistance to antibiotics.

The complete catalogue of all the technical advances with which British surgeons have been concerned would be long. But, reference must be made to the treatment of cancer by supervoltage irradiation, and by chemical substances which destroy the growing cells; to the operation for removal of the prostate gland which approaches it from outside instead of through the bladder; to the pioneer work on the pathology and treatment of diseases of the colon and rectum carried out at St. Mark's Hospital, London; to the scientific studies of the uses of the small intestine

for replacing diseased portions of the urinary organs, undertaken principally in Leeds and Liverpool; to corneal grafting—some of the earliest operations of this type were performed in Cardiff; and to the irradiation of the pituitary gland with radioactive 'seeds', first undertaken in London more than 30 years ago for disease of the gland itself, and recently introduced in Glasgow for the treatment of advanced cancer of the breast.

Furthermore we should not forget the help given to the surgeon in the investigation of his patients by injection of a radio-opaque medium into the spleen to demonstrate the circulation in the portal vein; and by cinematographic X-ray study of the movements of organs such as the stomach, intestine, or ureter, or of the circulation through abnormal blood vessels.

A separate article would be needed to do justice to the improvements in anaesthetic technique without which much of the surgery practised today could never have been undertaken. Suffice it to say that great credit is due to British anaesthetists for the high standards they have set, and for their own contributions to the advancement of their art.

It has been stated already that, in Britain, good surgery should be within reach of everyone. The distribution of surgeons is the responsibility of the National Health Service; their qualification to do good work is the responsibility of the Royal Colleges of Surgeons. These bodies have the education and training of young surgeons continually under review; they are represented on the Boards which make recommendations for the appointment of consultants; and their beneficent influence upon the standard of surgery has extended throughout the British Commonwealth.

Advances in the Realm of Medicine

BY LORD MORAN

When I was a medical student about 50 years ago, clerking to a physician in a medical ward was unpopular; students felt that physicians could do very little for their patients except to relieve their pain and ensure that they slept.

All this is now completely changed, and a medical ward is a cheerful place where nearly all the patients are going to get well soon, just as they do in a surgical ward. The discovery of antibiotics, by providing a specific cure for most of the acute infections, is responsible for this dramatic change.

For instance, in 1938, a new sulphonamide drug, active against the pneumococcus, was discovered by workers in the British firm of May and Baker. Up to that time pneumonia was one of the three major causes of death. Now it is, broadly speaking, a relatively mild malady.

The discovery of penicillin by the late Sir Alexander Fleming, working at St. Mary's Hospital in London, provided the world with an extraordinarily effective means of controlling the most severe infections with pyogenic bacteria. The story is familiar, how the penicillin mould blew in through a window and contaminated the culture so that when Fleming came to his bench in the morning, casually glancing at the slide he noticed that the growth of staphylococci had been prevented.

This observation was made in 1929, but it was not until ten years later that Sir Howard Florey and Dr. Chain, working in Oxford, were able to concentrate and purify the active principle so that it could be used on patients. The use of penicillin in World War II saved thousands of lives. Fleming was a contemporary of mine at St. Mary's and I am glad to think that in the evening of his day he received a Nobel Prize in 1945 after a lifetime looking down a microscope.

Malaria, until recently, caused more deaths and chronic ill-health in the world than any other single disease. The discovery

by Sir Ronald Ross, a Scotsman, that the malarial parasite is carried by mosquitoes began the successful crusade against the malarial parasite. Research workers in British firms have recently given us two important drugs, 'Paludrine' and 'Daraprim', which attack the malarial parasite in the liver and thus prevent relapses. Both these drugs have been used extensively throughout the world to control malaria.

Unfortunately the striking advances which have been made in combating the acute infections have not been associated with equal progress in delaying arterial disease in old people. Nevertheless, recent years have seen a definite advance in this field. Up to that time the treatment of hypertension was very disappointing. It was not until Professor Paton and Dr. Zainis, working at the National Institute for Medical Research in London, showed that hexamthonium, by paralysing the autonomic nervous system, could effectively control arterial pressure, that real progress was made. It was later tried, and found effective, in human hypertension, by Professor Resenheim and Dr. Arnold at University College, London. It is now used throughout the world, prolonging life in cases of malignant hypertension.

In North America and Northern Europe, degenerative arterial disease, including coronary artery disease, has become a major cause of death, often among men in the prime of life. An investigation of the causation of coronary thrombosis is therefore of the first importance. Dr. Fullerton of Aberdeen found that after a fatty meal there was a significant reduction in the time taken for blood clotting. Later, another British worker showed that men with sedentary occupations were more likely to develop coronary artery disease than those who had to take a good deal of exercise.

The world can see for itself that the discovery of penicillin was a benefaction to mankind. It is more difficult to explain that most dramatic discoveries are made possible only by the development of a new technique. Without attempting to describe partition-chromatography let me say this: in order to understand many disease processes, it is necessary to be able to study extremely tiny chemical changes taking place in the cells and fluids of the

body; chromatography is a new method of analysis, the possibilities of which are so revolutionary that it has been said that the old method could only be likened to the new if one thought of travel before the introduction of steam, and since. It is perhaps the greatest development in this field since the introduction of the balance to measure weights. The two British workers who discovered this method of analysis were awarded the Nobel Prize for chemistry in 1952.

Again, the full understanding of the structure of the protein molecule will have far-reaching results. Let me give a single example. If you take a page in a book, the words are composed of the 26 letters of the alphabet. But it is the sequence in which these letters are put down which determines whether the words make a sonnet by Shakespeare or just journalism.

In like manner, a protein molecule may be made up of 500 different amino-acids. If we call them bricks, then if one brick gets out of place a disease may develop. The useful haemoglobin, the colouring matter of blood, can become a form of anaemia common in the Mediterranean countries, by the displacement of a single 'brick'. Dr. Sanger, working in Cambridge, was awarded the Nobel Prize for clearing up the detailed structure of insulin.

It is sometimes said that moral progress in the world has not kept pace with the advances of science and in the same way our understanding of man's mental processes has lagged behind our knowledge of the physiology of his body. However, in 1929, Burger discovered that a pad-electrode tied to the scalp showed electrical changes, and Adrian, working at Cambridge, has made possible the use of the electro-encephalogram to detect abnormalities of the brain. The machine is now in routine use.

The National Health Service has decentralised British specialists so that they are scattered more evenly over the country, where formerly they were concentrated in the big cities. This has made it possible to upgrade hospitals in Britain by giving them a first-class staff, so that the whole population has profited by all these new advances in medicine.

Biological Effects of Low Temperatures

BY DR. A. S. PARKES

Nearly 300 years ago, in 1665, Robert Boyle published a series of remarkable essays on the effects of cold. His observations ranged from the preservation of food at low temperatures to the effects of cold on knights in armour. More relevant to the biological theme, he noted that frogs and fish were viable after being encased in ice for a day or two but not after longer periods.

Boyle, an outstanding figure in the history of chemistry, was a member of the group of natural philosophers who used to meet at Gresham College in London, and he was one of the members of the first Council of the Royal Society named in the Charter granted by King Charles II in 1662.

The study of the biological effects of low temperatures has therefore not only a long history, but the distinction of early association with the Royal Society.

In modern times progress has been most rapid, especially along three main lines.

First, the effect has been studied of reducing local or general body temperature in warm-blooded animals, especially mammals, to elucidate the physiological mechanisms involved in hibernation, the basic problems raised by the use of reduced body temperature in human surgery, and the nature of cold injury.

Second, the effects of cooling have been studied in cold-blooded animals, especially in lower animals and organisms which are subjected to sub-zero temperatures during part of their life-cycle.

Third, low temperatures have been used for the preservation in a test tube of lower organisms and of cells and tissues isolated from higher animals.

Warm-blooded animals typically regulate their internal temperatures within close limits, which vary somewhat from

species to species but are almost always between 37 degrees centigrade and 41 degrees centigrade. In much of the world, therefore, the body temperature of the warm-blooded animals is far above the environmental temperature, and in some instances the difference may be astonishing. The Emperor Penguin, for instance, not only supports life but contrives to incubate eggs and care for the chicks in Antarctic temperatures approaching minus 60 degrees centigrade.

Insulation against the environmental temperature may be achieved by layers of feathers, fur, or fat, and heat loss may be minimised by special mechanisms which enable especially exposed parts, such as the feet, to fall below the general body temperature.

An extension of this principle is seen in hibernation, which enables many adult animals and apparently some birds to deal with periods of cold or food shortage. In this condition the body temperature falls to, and is controlled at, a much lower level as though a thermostat had been reset.

Hibernation, however, is not a state of suspended animation, because heart-beat and respiration continue at a slow rate and body temperature is not allowed to fall to a level at which body water would be converted to ice.

Laboratory experimentation has extended this picture greatly. Until a few years ago it was thought that an adult non-hibernating animal such as the rat, could not survive being cooled to a deep body temperature below 15 degrees centigrade at which point heart-beat and respiration fail.

This view, however, was exploded by the work of Radoslav Andjus, of the University of Belgrade, who showed that, by special methods, rats, mice and dogs could be revived after cooling to deep body temperatures of zero centigrade, although heart-beat and respiration had been arrested for an hour or more. Rats so treated showed no impairment of memory or learning capacity.

More remarkably still, it was found by Audrey Smith, working at the National Institute for Medical Research in London, that the Golden Hamster, which probably hibernates in nature, could

be resuscitated undamaged after supercooling to minus 5 degrees centigrade or freezing to the point where 50 per cent of the body water crystallised as ice.

In man, body temperature is now commonly reduced to about 28 degrees centigrade for surgical purposes, but, at this temperature, the heart is still beating slowly and natural breathing can, if necessary, be supplemented by artificial respiration.

This work raises intriguing philosophical problems. At zero centigrade the artificially-cooled mammal has every appearance of being dead and by all clinical criteria is dead. Yet, by appropriate treatment, it can be revived.

How then are we to define death? The biologist can answer only that death is the state from which resuscitation of the body as a whole is impossible by any currently known means. As the means of resuscitation extend, a condition which constitutes death today will not necessarily constitute death tomorrow.

In contrast to the warm-blooded animals, cold-blooded animals have little control over their internal temperature, which tends to approximate to that of the environment, and many readily withstand body temperatures down nearly to zero centigrade, at which their vital processes are slowed down but do not cease. Even higher cold-blooded animals thus have a great tolerance for temperature changes, but it is now thought that many may have some power of regulating their internal temperature when in danger of being frozen, which is as lethal to them as to warm-blooded animals.

The widespread popular belief that fish can be revived after being frozen stiff in blocks of ice probably arises from the fact that fish will survive for a time freezing of the surface of the body, and partly from the assumption that a fish encased in ice is itself necessarily frozen.

Considerable success was achieved even by the early workers in the freezing of isolated cells and tissues from lower organisms. Normal material from the higher animals, especially mammals, proved to be much more sensitive to the effects of freezing and thawing, and up to 1949 there were very few reports of even partial revival of such cells and tissues after freezing.

In that year, Audrey Smith and Christopher Polge, working at the National Institute for Medical Research in London, observed that the addition of glycerine to the suspending medium had a remarkable effect in protecting fowl spermatozoa against the otherwise fatal effects of freezing to minus 79 degrees centigrade (solidified carbon dioxide) or even to minus 192 degrees centigrade (liquid air). Such spermatozoa after thawing and removal of the glycerine retained good capacity to fertilise the egg.

The same kind of protective effect of glycerine was found by Audrey Smith in the case of rabbit and human red blood cells which are normally destroyed by freezing and thawing. The frozen red cells, after thawing and removal of the glycerine, could be used for transfusion and had a normal life history in the recipient animal or person.

Shortly after the discovery of the protective properties of glycerine, Smith and Polge turned their attention to freezing bull semen, partly because of the abundance of the material and partly because of its economic importance.

Bull spermatozoa proved to be more sensitive than fowl spermatozoa, and not only the use of glycerine but also slow freezing, a procedure contrary to all then existing ideas, was found to be necessary. Under these conditions a large proportion of bull spermatozoa could be revived after freezing to minus 79 degrees centigrade and showed normal fertilising power on insemination even without the removal of the glycerine.

The idea of using glycerine or other protective substance combined with slow freezing has now been extended to many other cells and tissues.

Ovarian eggs have presented some difficulty, but a small proportion revived in a viable state after being treated with glycerine and slowly frozen.

Considerable success has been achieved with bone marrow and spleen, and ovarian cells, adrenal and kidney tissue, and cartilage have all been found to survive as grafts or in tissue culture after preservation at low temperatures in the presence of glycerine.

A rational approach to the problem of avoiding the damage caused by freezing and thawing depends on knowing the cause

of that damage, but so far progress in this field has mainly taken the form of empirical discoveries which later have to be explained.

The simplest idea of the nature of freezing damage is that it arises from mechanical pressures and distortions caused by the formation of ice crystals, and a good deal of work by Luyet and others in the United States of America was devoted to developing methods of ultra-rapid freezing during which there would not be time for ice crystals to form. This work had a limited amount of success, though probably not for the reasons supposed.

A more serious hazard to frozen tissues was emphasised by T. Moran, working in Cambridge, England. He pointed out that when water crystallises as ice the residual fluid becomes more concentrated, especially in its salt content, and the tissue is literally pickled in its own brine.

No doubt other factors are involved, but following the work of J. E. Lovelock at the National Institute for Medical Research in London, it is likely that toxicity of the concentrated residual fluid is the most important single cause of freezing damage. In this case it may be supposed that the effect of glycerine is to make the residual fluid, in which the glycerine as well as other things will be concentrated, less damaging to the cell.

The beneficial effects of slow cooling in some instances seems to depend on its affecting the position of the ice crystals and preventing the damage known to be caused to many types of cells by very rapid changes in temperature. In this connection it is of special interest to note that the larvae of the Goat Moth, which are remarkably frost-hardy, substitute sugar for salt in their blood as winter approaches; and that insects of several different species in the U.S.A., Canada and Japan, which are subjected under natural conditions to very low temperatures during the winter, prepare for the winter by themselves making glycerine.

The effects of cold are of interest to biologists for many reasons, but much of the work has been inspired by the idea of long-term preservation of living material.

At very low temperatures the biochemical processes of life are arrested or greatly retarded, so that if a cell can be frozen and

thawed without damage it should be possible to maintain it in a state of suspended animation at low temperatures.

Instances of such a state occurring regularly for short periods under natural conditions in lower organisms are well known, and laboratory work of the last decade has opened up exciting possibilities of the long-term preservation of cells in test tubes, such as spermatozoa for insemination, ova for transference to another animal, red blood cells for transfusion, and tissues and whole organs for transplantation.

Beyond these more or less realistic ideas are thoughts of whole animals, possibly even man himself, preserved in a state of 'suspended life' induced by cold.

Some of these dreams have already been realised. Bull spermatozoa frozen in Cambridge more than six years ago still retain fertilising power. Human spermatozoa have retained fertilising power after storage at minus 79 degrees centigrade for some weeks, and human red blood cells have been preserved for transfusion for more than two years by means of the glycerine freezing technique.

More recently, bone marrow has been found to retain its capacity to protect against whole-body irradiation for many months under similar conditions, and little imagination is required to see the potential value of this development. Among tissues, human cornea has been successfully preserved, for grafting, for many months at minus 79 degrees centigrade.

Effective extension of this work to the whole mammal will take a long time. The possible duration of suspended animation in mammals at ordinary body temperature is severely limited by the rapid breakdown of the elaborate biochemical systems of the body and the onset of irreversible changes.

The same is true to a lesser extent at a body temperature a few degrees below zero centigrade, the lowest point from which mammals have so far been revived. The condition of the cooled or partly frozen animal is therefore a very unstable one, and no prolonged survival can be expected at this temperature.

For long-term preservation in the frozen state, a temperature in the range already known to be required for individual cells and

tissues will presumably be necessary, and with it the pre-treatment of the animal with some such substance as glycerine.

The biologist, therefore, is not obviously near to achieving suspended animation of a warm-blooded animal at a temperature likely to result in a stable state, but he may do so unexpectedly at any moment by some ingenious stroke.

Continued developments in this field are likely to make a major contribution to man's powers over nature, and to show that biology, though overshadowed at the present time by physics, chemistry and engineering, is not backward in modern discovery and invention.

First in the Jet Era

BY AIR COMMODORE SIR FRANK WHITTLE

On 12th April, 1937, the first turbo-jet engine in the world made its début in the turbine factory of the British Thomson-Houston Company, at Rugby, England.

I stress 'first in the world' because many people still believe that we were beaten to it by Germany, whereas in fact, though von Ohain, working within the Heinkel organisation was close behind, his engine first ran in September 1937.

In retrospect, our first engine, known as 'W.U.' (Whittle Unit), was remarkable for many reasons apart from the fact that it was the first.

It made its first run almost within a year of the start of design drawings; it was built at a cost of about £3,000; it started up on the first attempt (and accelerated out of control up to half full speed); after its second reconstruction in 1938 it was the basic prototype of a large family of British and American jet engines; it survived nearly four years of development running before being wrecked beyond repair, and during that period was used to break the back of 90 per cent of the development problems of the type.

Also it was designed as a test bench version of a flight engine intended to make possible a transatlantic mail carrying aircraft capable of cruising at 500 miles (800 kilometres) an hour. As everyone now knows, the brilliant achievements of the de Havilland Comet 4 have proved that we were not wild visionaries in setting this target.

But Britain's lead in the jet engine and turbo-prop field is by no means entirely due to the Whittle series of engines and their near relatives. Some two or three years before I applied for my first patent in January 1930, a scientist working at the Air Ministry's South Kensington, London, Laboratory, and later at the Royal Aircraft Establishment, Farnborough—Dr. A. A. Griffith—had convinced himself (and at that time, only himself) that a propeller gas turbine was both feasible and desirable.

In this he was later joined by a staunch supporter in Hayne Constant. But though Griffith and Constant were allowed to make a few experiments with axial flow type compressors, it was not until our first engine provided the stimulus that the Air Ministry began to take their ideas seriously and authorise the design and construction of the engine known as the F.2.

This engine was built by Metropolitan-Vickers at Manchester. It started its life in the design stage as a propellor gas turbine, but in the light of the progress we were making with our simple jet engine, it was decided to redesign the F.2 as a jet engine. Although, for many years, policy decisions and complexities of design and construction retarded the progress of the axial flow type of engine, nevertheless, the F.2 without doubt, shares, with the W.U., the parentage of most modern jet engines and turbo-props.

This is but a very bare outline of events which have led to a revolution in aircraft performance. The gas turbine has almost ousted the piston engine in all except light aircraft. Bomber Command and Fighter Command of the Royal Air Force (and the corresponding air force arms of most other countries) are entirely jet propelled. Transport Command, with its Comet 2s, is largely jet propelled and, with the acquisition of Bristol Britannias, will become mainly gas turbine engined.

In the realm of civil aviation, the gas turbine is sweeping the field and has enabled Britain to make big inroads into what was once almost an exclusively American sphere. The Vickers Viscount, powered by Rolls-Royce Dart turbo-prop engines, has been in service for several years now and hundreds have been sold to overseas airlines. It is becoming as dominant in the medium range field as was the Douglas D.C.3 in the past. In the class of long-range turbo-prop aircraft, the Bristol Britannia remains unrivalled.

But in my opinion the highlight of modern civil aviation is the Comet 4, which has risen gloriously from the ashes of the Comet 1. To me the Comet has special significance—it has more than fulfilled our original targets.

Many of these things have taken longer to come about than I expected. Much of what has been done could, I think, have been done

years ago, but on the other hand, performance has far surpassed anything I would have dared foretell in 1937. Before the advent of the jet engine, the increase in the world air speed record averaged 12 miles (19 kilometres) an hour per year, but since the Gloster Meteor IV established a record of 606 miles (975 kilometres) an hour in 1945, the increase has averaged more than 60 miles (96 kilometres) an hour per year.

Since the end of the war the power of jet engines has been doubled and re-doubled. In spite of this progress there is still much more to come, and I for one would not dare to predict an upper limit to speed in the air. However, for the next decade or so I think that the cruising speeds of civil aircraft will be stabilised in the 400 to 500 miles (645 to 800 kilometres) an hour range for turbo-props and in the 500 to 650 miles (800 to 1,045 kilometres) an hour range for pure jet aircraft.

But the supersonic airliner is inevitable sooner or later; and in my view, the immediate cruising speed target should be about 1,500 miles (2,415 kilometres) an hour. At this speed the jet engine operates with very high efficiency, while aerodynamic heating problems should not be too difficult. How soon this target will be achieved depends more on the skill of aircraft designers than on engine development, though the latter will, of course, play its part.

To me, one of the most satisfying aspects of Britain's prominent role in the jet age is the astonishing rise in the exports of the aircraft industry—now running at the rate of about £160,000,000 a year. Britain must import about half her food and a high proportion of her raw material needs, and these imports can only be paid for by exports, so it can truly be claimed that the aircraft gas turbine is helping to feed the nation. For this reason alone, it is important that Britain should maintain its position in the van of progress.

Great Step Forward in Agriculture

BY PROFESSOR H. G. SANDERS

In Britain there are roughly 30,000,000 acres (12,140,000 hectares) of farmed land with a further 16,000,000 acres (6,475,000 hectares) which are classified as 'rough grazing' and which consist mainly of hills. There are some large farms, but small ones predominate. Disregarding the smallest (often worked on a part-time basis), approximately two-fifths of farms are less than 50 acres (20 hectares), another two-fifths lie between 50 and 150 acres (20 and 60 hectares), leaving only one-fifth with more than 150 acres (60 hectares).

Despite its small size, the country varies much in its farming conditions. The south and east parts are generally flat, with annual rainfall from 20 to 30 inches (50 to 75 centimetres); here arable farming is important. Further north and further west the rainfall is higher and the land more hilly, with the result that the land is mostly under grass and livestock play a bigger part in farming systems. For the country as a whole, 63 per cent of the farmed land is grass, either permanently or temporary grass sown down for from three to seven years; the range of variation between counties in this grassland percentage is as wide as from 15 to 85.

Agricultural production has increased by 60 per cent since 1939, despite loss of land to buildings, roads, and so on, and a fall of 10 per cent in the number of workers on farms. Crop yields per acre have risen by about one-third, as have milk yields per cow, which now average 750 gallons (3,400 litres) per year for all the cows in the country.

Many things have contributed to increased efficiency. Mechanisation has played a big part, the number of tractors have increased tenfold to the present figure of about 500,000. The first stage of mechanisation—the simple displacement of horses by tractors—is now virtually complete and good progress has been made with the second stage, which is the equipping of the tractor with its own implements and controls so that it can do much that horses

could never do. More advances in mechanisation will certainly come, and already the first faltering steps in the application of electronics to farming have been taken. Fertiliser usage has reached a high level, though there is room for more generosity to grassland, and application of lime, favoured by government grant, is well organised so that acidity now rarely limits production from the land.

In the past British farmers have had great successes in developing breeds of cattle, sheep and pigs which have gone far and wide over the world. Continuing improvement becomes ever more difficult and requires the application of modern genetical techniques. Over 60 per cent of all the cows in Britain are now served by artificial insemination, and this has halved the number of bulls required, giving great opportunity for selection on the male side. The only safe assessment of a dairy bull is made on his daughter's yields, and ever greater weight is being placed on these progeny tests. At the same time a 'Selective Mating Scheme' is in operation, whose object is to breed young bulls likely to prove successful sires. This means the planned mating of carefully chosen bulls and cows which may be geographically far apart.

A start has been made along similar lines with beef bulls and there are five progeny testing stations for pigs and three for poultry, so there is reason to hope that Britain may maintain her proud record in livestock improvement. The aim must be not only to breed better livestock but also to keep them in health. Foot-and-mouth disease is dealt with by slaughter and bovine tuberculosis has been almost eradicated. The plan provided that the whole country should be virtually clear of the latter by the end of 1960. Progress in the control of other diseases is being made, though, naturally, at varying rates.

Most governments support their agriculture in one way or another, and the degree of support for British agriculture is about the average for all countries where farming may be said to be advanced. In Britain 12 commodities, for example, wheat, milk, pigs, have their prices guaranteed by the State, which also makes production grants (up to 50 per cent of the cost) for good farm practices, such as draining and improving farm buildings. There

is also special help for small farmers and for those with land of marginal agricultural worth. The guarantees and the grants are reviewed annually in consultation with representatives of the farmers, but there are provisions which limit the amount by which support can be lowered in any one year. Farmers have security in the sense that they know they will not be faced with any sudden and catastrophic fall in the prices they receive for their products.

In return for the support it gives, the Government expects that farmers shall continue the improvement in efficiency which has been so marked in the last 20 years. Anyone familiar with British farming before 1939 would scarcely recognise it today. Progress has been due largely to the great scientific advance that has occurred since then, and it is certain that only by further application of science to farming can progress continue.

The Agricultural Research Council has 23 research institutes, staffed with highly trained scientists, in addition to supporting promising lines of research work in universities. It is the task of the extension services to bring new scientific knowledge to the farmers and to help them to adopt new methods and new ideas to their own farms. The extension services have 12 farms and six horticultural stations of their own, on which new things may be tried out under a variety of conditions and to which farmers can go to see the results.

The best techniques do not necessarily lead to financial success in farming. For that, the right methods and the right systems are both necessary. Consequently, in the last few years extension officers have been paying special attention to questions of farm management, to the planning of operations and to the economic use of labour.

This may require, for an individual farmer, a detailed analysis of his present methods and the comparison of his results with economic standards (for example, net output per unit of labour) or it may merely entail estimating the gains and losses which would result, say, from the introduction of a new machine. This work can be time-consuming, but it is very rewarding. The aim is to raise both technical and economic efficiency to the highest

level. All this is going steadily forward. Indeed, the rate of progress is accelerating and it is safe to prophesy that the next two decades will see even more advance in British agriculture than has been achieved in the last 20 years.

Developments in the Uses of Nuclear Power

BY SIR JOHN COCKCROFT

The progress towards the large-scale development of nuclear power has been one of the most remarkable achievements of the post-war era.

In 1937, in spite of the great discoveries in nuclear physics during the preceding five years, Rutherford in his last lecture said that 'the outlook for gaining useful energy from the atoms by artificial processes of transformation was not promising'.

The key to nuclear power was, however, found within a year of Rutherford's death by the discovery by Hahn and Strassman of the fission of uranium. They found that the elementary particles —neutrons—discovered by Chadwick in Cambridge in 1932— could cause the heavy nuclei of uranium to split into two high-speed fragments. These fragments were found by other workers to throw out neutrons and these could obviously be used to produce more fissions—so a chain reaction was seen to be possible in principle. The energy released in the fission process was found to be very high—the energy released by the fission of one gram of uranium being equal to that released in the combustion of three tons of coal.

The war years brought this to a practical realisation with the construction of the first atomic pile by Fermi and his colleagues in December 1942. The Fermi pile consisted of a pile of blocks of pure graphite interspersed with bars of uranium metal and uranium oxide. The uranium nuclei split up spontaneously at a low rate and throw out neutrons. These cause further fissions and these produce more neutrons. If the birth rate of neutrons exceeds their death rate, the chain reaction builds up—it is said to be divergent. But it can be brought into a steady state by inserting control rods containing boron or cadmium which swallow up

neutrons so that the birth rate and death rate can be made equal. The function of the graphite moderator is to slow down the neutrons emitted in fission from their initial high speed to lower speed where they are more efficient in producing further fissions, but they do that only in the light isotope of uranium U.235—present in one part in 140 of the whole.

It took 14 years to progress from Fermi's simple graphite pile to the first large-scale nuclear power station at Calder Hall.

In Britain we decided to adopt the graphite pile as our route to nuclear power for a variety of practical reasons. When we formed our Atomic Energy team in Britain we found it easiest to build graphite-moderated reactors because we could produce all the special materials ourselves or in the Commonwealth. Our first two reactors at Harwell, 'GLEEP' and 'BEPO', were of this type, and they were followed by two much larger reactors at Windscale designed to produce plutonium for military purposes.

Our first use of nuclear energy was to heat some of our Harwell buildings—to produce 'atomic hot water'. The energy contained in the flying projectiles of fission of uranium heats up the uranium metal bars of the pile and this heat is removed in 'BEPO' by flowing air past them. The hot air passes over a heat exchanger, and so we get our atomic hot water.

The Calder Hall nuclear power station uses the same basic principle. The two nuclear reactors of the power station are contained in steel pressure drums 37 feet (11·277 metres) in diameter. Each reactor contains 1,200 tons of graphite blocks and 130 tons of uranium metal sheathed in a magnesium alloy. The energy of fission raises the temperature of the uranium fuel elements to a maximum of 408 degrees centigrade. This heat is transferred to four heat exchangers by circulating carbon dioxide under a pressure of seven atmospheres. Water in the heat exchanger is heated and steam is raised and then passes to a conventional power station where gross output of 90 megawatts of electricity is generated.

The Calder Hall power station was built primarily as a plutonium producer, with electricity as a by-product. We have had

several years of operating experience, and this has on the whole been very satisfactory. One of the four reactors operated continuously for six months—an indication of its reliability.

The success of Calder Hall led to a programme of construction of nuclear power stations by the Electricity Boards. The Government's object in developing nuclear power was to provide an additional source of energy to meet our rapidly increasing needs.

Economic forecasts showed that our energy requirements would increase by 50 per cent between 1955 and 1975—from 250,000,000 tons of coal equivalent to 360,000,000 tons. Coal production had been about 220,000,000 tons, and in spite of the large capital investment programme is not forecast to grow much beyond this level. The nuclear power programme of 5,000–6,000 megawatts by 1966 was decided on.

By 1965, the British Electricity Boards will have built nuclear power stations at Bradwell, Berkeley, Hunterston, Hinkley Point, Trawsfynydd and Dungeness, developing a total of about 2,400 megawatts. A further power station at Sizewell in Suffolk is proposed. Except for Trawsfynydd, which is on an artificial lake, they are located on the coast because, like all large power stations, they require a lot of cooling water and suitable river sites are now scarce. They are also located away from coalfields, because coal-fuelled power stations located on the coalfields will satisfy nearby users, so it is obviously economic to site nuclear stations on distant sites where coal costs would be higher.

The Electricity Board power stations are typified by Hinkley Point power station in Somerset, which is to develop 500 megawatts of electricity. It will have two reactors, each of them containing 370 tons of uranium metal fuel. The reactors are contained in large spheres 70 feet (21·336 metres) in diameter, and carbon dioxide will be circulated as a coolant. A later power station will develop 600 megawatts.

We have not so far developed nuclear power stations of the pressurised water or boiling water type, because they use enriched uranium which costs about twice as much to produce in Britain as in the United States, and our production of enriched uranium is much less. They would not be economic in our country using

United Kingdom enriched fuel, in spite of the capital costs being lower than those of the graphite-moderated, gas-cooled reactor types.

In the future, as our large-scale nuclear programme comes into being, our natural uranium fuelled power stations will produce large amounts of plutonium as a by-product. This is a valuable nuclear fuel which it may be possible to use to provide enrichment by adding it to natural uranium, and so increasing the proportion of the fuel which is fissioned by slow neutrons.

The next phase in the development of nuclear power stations aims at achieving a major reduction in capital costs while retaining fuel costs at their present low levels.

In order to do this we aim at increasing the temperature of operation of the fuel elements from 430 degrees centigrade to about 600 degrees centigrade. This will enable the steam pressure and temperature to be raised so that the cost of the conventional part of the power station can be reduced appreciably. In the 1960–67 power stations this part of the power station costs as much as the whole cost of a conventional power station.

We will also increase the amount of heat we can extract from each ton of uranium about three times. To do this we will split up the fuel elements into a cluster of small-diameter rods. The fuel elements will have to be uranium oxide, because metal would be too soft at the higher temperatures. We will also have to abandon our magnox sheaths and use beryllium metal—if we can develop its technology soon enough. Failing this we shall have to use stainless steel.

Another type of reactor favoured for our longer term programme is the so-called 'Fast Breeder Reactor'. The fast reactor of the future will probably consist of a small core of plutonium oxide interspersed with some uranium. The core will be surrounded by a so-called 'blanket' of natural uranium or depleted uranium. The chain reaction proceeds in the core and the neutrons are slowed down only by collisions in the uranium or plutonium. They produce further fissions while they are moving fast. The overall result of this is that in a plutonium-fuelled fast reactor, for each primary plutonium atom destroyed, about 1·5 new ones will be produced

by capture of the neutrons in U.238. So the reactor is said to breed —it breeds plutonium from the abundant heavy uranium.

The long-term advantage of the fast reactor is that it will enable us to make use of a large part of the fissionable energy of U.238, whereas the earlier—so-called thermal reactors—rely mainly on the fission of U.235, which is less than 1 per cent of the total uranium.

So, to make the fullest use of the energy in uranium, we will have to develop breeders.

The time scale for fast breeder reactor development, however, is set by the availability of the large amounts of plutonium for the initial charge of the core. A future fast reactor power station may require as much as half a ton of plutonium for a charge. We can envisage a programme of construction of large-scale fast reactor stations starting in the 1970's.

We have made a start by building a fast reactor experiment at Dounreay, and since its start-up in November 1959 we have been acquiring the operating and technological experience necessary for the design of a prototype of a future fast reactor power station.

Nuclear fission could ensure the world's energy reserves for many centuries. Beyond that, or before that, we have the alluring prospect of drawing energy from the fusing together of light nuclei. The sun and the stars have been using this source of energy for billions of years, and it is a tremendous challenge to science to harness the energy of fusion of light nuclei. We are playing a leading part in research on this fascinating project.

Development in the Thermonuclear Field

BY SIR GEORGE THOMSON

During World War II, the joint efforts of the nuclear physicists of Britain and the United States of America were concentrated in a feverish attempt to produce an atomic bomb from uranium or some substance derived from it. The type of reactor, or pile as it was first called, which has since been developed for power at Calder Hall and Britain's other nuclear stations, was originally designed to produce the plutonium which composed the bomb dropped at Nagasaki.

Britain has had less to do with the production of the hydrogen bomb, but more to do with the development of the attempt to use the same source of energy for peaceful purposes. It is one of the consequences of Einstein's famous formula connecting mass and energy that one can predict from laboratory measurements which substances are potential sources of nuclear energy, even though one can suggest no way of actually releasing it.

One of the most obvious is deuterium, the 'heavy hydrogen' discovered by Urey and his collaborators and present to the extent of one part in 6,000 in all hydrogen, including that in the sea. Even before the end of the war some of the workers at Los Alamos, U.S.A., had toyed with the idea and done a few back-of-an-envelope calculations on what it would involve and what one might hope to get. Shortly after the end of the war, workers at Imperial College, London, and at Oxford under the late Lord Cherwell, became interested, but our interest was fixed on the peaceful applications.

It is a curious feature of the problem that the nuclear aspect is straightforward and depends on experiments made by Rutherford and Oliphant at Cambridge in the early 1930s. Deuterium will undoubtedly give power if certain conditions can be established,

and these conditions can be calculated in advance. They turn out to be formidable. Temperatures in the region of 100,000,000 degrees centigrade or more are needed. For comparison, the temperature of the surface of the sun is less than 6,000 degrees, and the highest temperatures produced artificially before this project started had been of the same order. Even the temperature of the centre of the sun, according to the best available estimate, is only 15,000,000 degrees.

There is a further requirement to ensure that the nuclear energy produced exceeds that used in heating the deuterium, namely that the temperature must be maintained for a time which depends on the density of the reacting deuterium. If the density can be relatively high, say that of a normal solid, the release of energy, once the temperature is reached, is extremely rapid and the heat has no time to escape. In other words, there is an explosion. This has been achieved in the hydrogen bomb.

No very serious attempt has been made to adapt the techniques of the hydrogen bomb to the continuous production of power, for example by a rapid series of relatively small explosions. The difficulties are sufficiently obvious, but the possibility should not be quite excluded.

All the efforts that have been made have taken the other line of attack, have assumed that the process, if intermittent at all, must be made to last for at least a reasonable fraction of a second. While this avoids an explosion and allows the use of low densities, thus easing the problem of handling the energy when produced, it brings one up against the problem of heat insulation, or 'containment' as it is often called. How is one to prevent the heat produced by a current in the gas or some other method, from leaking away so fast that the temperature will never reach anything like the necessary height? It seems generally agreed that there is only one way in principle, though it has many varieties in practice. A magnetic field, that is, the space near a magnet or an electric current, in which magnetic effects can be observed, has a containing effect on a gas such as deuterium once it has reached a certain temperature, high indeed by ordinary standards, but very much less than that we need. The magnetic field, if strong and

suitably arranged, can, in theory at least, prevent the hot gas from touching the walls of the vessel, holding it away from them as a crowd might be held back from a line of soldiers by fear of their weapons. This should prevent the most serious, though not the only, loss of heat. Another loss, due to radiation in its technical sense, has simply to be accepted. And in consequence of this cooling effect the necessary temperature to which the deuterium must be raised before the nuclear fire will start and keep alight comes out as 400,000,000 degrees. If a mixture of deuterium and tritium is used one can get away with 45,000,000, but the tritium has to be made from lithium.

These principles can be established by fairly simple calculations, and it was clear enough as early as 1946, to those of us who were working on the problem in London, what needed doing. It is a very difficult matter to do it. The demand was to heat up deuterium to many million degrees and to keep it away from the walls of the vessel, containing it for a matter of seconds—a very long time by these standards. The magnetic fields needed to do this are very high, too high for permanent steel magnets, and besides, the very hot gas (so-called 'plasma') would follow the lines of magnetic force which lead straight into the poles of such magnets.

It is essential to have an arrangement in which the lines of force run round in closed loops. Such an arrangement is possible in a vessel called a torus, shaped like the inside of a motor tyre. If a current is sent through a coil of wire wound round the tyre the right kind of field is produced. However, after a talk with Professor Peierls of Birmingham I discarded this idea, as it seemed likely that currents set up in the gas would nullify the magnetic field. Instead, I used the idea of a re-entrant current in the gas itself. Circular currents of this kind had been known for a long time in physics; my father (Sir J. J. Thomson) worked with them as far back as the 1880s. Such a current in the gas inside the tyre, if strong enough, should draw the gas away from the walls on all sides. To picture this, imagine the inner tube of a bicycle tyre inflated inside a motor car tyre of equal wheel diameter, and suppose that the inner tube is held away by some invisible force, representing the magnetic field, from touching the outer case.

I suggested this idea in 1946, and experiments were begun on a small scale by Dr. A. A. Ware at Imperial College in 1947. About the same time Dr. Tuck, now leader of the U.S. team at Los Alamos, began work at Oxford on similar lines, and Dr. Thonemann, an Australian who had thought deeply on the problem before going to Britain, started actual experimental work there in 1948.

No special attempt was made to preserve secrecy, though the United Kingdom Atomic Energy Authority gave some assistance towards the apparatus, till 1950. In that year the Authority felt that the prospects of success, which at first had seemed to them remote, were appreciable, and since, as a by-product, such a device could make plutonium for bombs, decided that the work must be classified. Accordingly in that year the project became secret, and in 1951 the Oxford work was moved to Harwell under Thonemann and the London work to the Associated Electrical Industries Ltd. Research Laboratory at Aldermaston, where Ware headed a team under the supervision of Mr. Chick and Dr. T. E. Allibone, the head of the laboratory. This arrangement has continued since, with a very close liaison between the two groups.

The greatest difficulty has been that arrangements which should have retained the plasma if it had remained quiescent have been found to lead to instabilities. Instead of the plasma behaving as a collection of independent electrons and nuclei, mass motions occur, as though the crowd, instead of being a group of individuals, began to act on a concerted plan. It is mainly for this reason that no device so far, with some very doubtful exceptions, has achieved a true thermonuclear reaction even at a low level of intensity.

As a result, Harwell produced the well-known device, ZETA, and A.E.I. shortly afterwards the rather similar SCEPTRE. It was thought at first that both these devices were producing a genuine thermonuclear reaction, though a feeble one. It is thought now that this is not the case, and that the reactions observed are, like those reported earlier by the Russians, due to secondary causes, which, unlike a true thermonuclear reaction, cannot be enormously multiplied simply by increasing the current through the gas. One of the great difficulties of this work from the start

has been to find reliable ways of measuring what is actually going on in a gas carrying a current of about 200,000 amps at a temperature which must be somewhere in the million degree range.

Though compared with some earlier devices of the same kind both ZETA and SCEPTRE are relatively stable, they certainly are not completely so, and it is perhaps some satisfaction that this accords with the best existing theories.

Since 1956, information has been freely exchanged between Britain and the U.S., and, since 1958, with the world. The U.S. effort is known as Project Sherwood and started in 1951.

A large amount of work has been done in the U.S. on the pinch discharges, especially at Los Alamos and Livermore in California, and much valuable information obtained, but so far nothing has been produced which is an improvement on ZETA, though it might be claimed that the U.S. has concentrated more on basic information and so less on prototypes of possible working devices. Much the same holds for the less extensive work in the Soviet Union. There is still much basic work to do, and the present programme in Britain is directed to improve basic knowledge of plasma.

Two other quite independent ideas are prominent in the work of Project Sherwood. The first, due to Lyman Spitzer at Princeton, U.S., is to use the magnetic field produced by currents in coils wound round the torus to contain the gas. But he finds the torus must not be an ordinary one; it has to be twisted into a figure-of-eight. This device Spitzer, originally an astronomer, calls a stellerator. It also has had troubles from instabilities, not too clearly understood. The stellerator and the pinch device seem to be converging, for ZETA and SCEPTRE include an auxiliary magnetic field produced by currents outside, while the later models of the stellerator provide for a substantial current through the gas. The stellerator also includes ingenious devices for purifying the gas, and for what is known as magnetic pumping. This is a means for heating the gas in the later stages; the early stages of heating are done, as in pinch devices, by current in the gas. A very large stellerator is now under construction but it is not expected to be a power producer.

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Finally, the so-called mirror machine of Dr. Post's group at Livermore is a most ingenious way of using external magnetic fields by which the plasma can be held and, if desired, compressed in an invisible 'bottle' of magnetic fields. The chief difficulty here is in the early stages, for, until it is very hot indeed, the gas leaks out of the ends of the 'bottle', and it is difficult to heat it quickly enough in place. It is almost equally difficult to give it a preliminary heating elsewhere and then introduce it into the 'bottle', for the fields which keep the particles in also prevent them from entering, but in fact quite promising ways of doing this are being studied.

The Russians have built an enormous experimental machine on these lines called 'Ogra', though some people doubt if their proposed method of admission will work. 'Ogra' is now being tested, but because of its size it will probably be some time before it is known how far it is a success.

The experiments are all on a fairly large scale and therefore expensive, and it looks as if any useful device will also have to be large. Such a device will be a very powerful source of neutrons, and as these are a commodity of great value to the nuclear engineer concerned with fission, it is not unlikely that the first practical use may be as a neutron source, the power being regarded as a by-product. This power would come out mostly as heat, but some could be extracted directly as electrical energy, which, of course, is greatly to be preferred. It is impossible to predict the cost of power from a device not yet made or to say if it will be able to compete economically with other sources, but to learn how to produce power from the virtually limitless quantities of deuterium in the sea would set mankind free for ever from fear of a power shortage, whatever demands are made.

Exploring the Worlds of Sand and Ice

BY PROFESSOR FRANK DEBENHAM

Tradition dies hard in any nation, and in the field of Exploration the contribution from Britain is still as steady in its second Elizabethan age as in the first. The footsteps of Man continue to press out into the unknown and many of them start from our small islands.

The pattern may have changed, but the spirit endures, and it can be expressed either in Kipling's phrase as the urge 'to go and find out and be damned' or in Mallory's neater one, to attempt to climb Everest simply 'because it is there'. That was the spur behind Hillary and Tenzing when they reached the summit in 1953.

There are vast areas to be explored in the bed of the ocean, but on land the unknown has shrunk so rapidly of recent years that it is now almost confined to deserts alone: hot deserts of endless sand and cold deserts of limitless ice.

The footsteps of Britons are to be found in both, often leading the way, whether those of Bertram Thomas across the Empty Quarter of Arabia, of Fuchs and Hillary across Antarctica, or of Simpson and his men across Greenland.

The technique of transport has altered so much that there are now strange parallel tracks following the footsteps of Scott and Shackleton to the South Pole and others along the camel-pads of Rennell Rodd in the Sahara and of St. John Philby across Arab plateaux. What was difficult to one generation becomes easy to the one that follows, and the pioneer track of one decade may become a highway in the next. The Ewart Grogan who, 50 years ago, walked from the Cape to Cairo in three years is still alive to read of competitions to drive the same way by car in a matter of days, or to fly in a matter of hours.

These mechanical aids to travel have narrowed the scope of the single-handed explorer. Yet Charles Doughty has had a recent successor in the wanderings of Wilfred Thesiger through southern Arabia and Abyssinia; while Mary Kingsley in West Africa of the last century has been followed by Gertrude Bell in Arabia and by Freya Stark in her recent hazardous walk over Asia Minor with a donkey. An essential feature in these desert journeys was that the explorers all had to be proficient and even scholarly in their knowledge of Arabic, without which they could not have gone far.

In the polar regions, where the lone traveller can rarely carry out useful exploration, British expeditions have developed a characteristic of their own. They tend to be small, their members youthful, their efficiency high and their cost low.

It was a brilliant young man, Gino Watkins from Cambridge, who first introduced this standard in 1930, and his expedition of 14 young men, exploring an air route across Greenland, has become a classic for the amount of work done and the new methods evolved. All were unpaid volunteers. Nearly all learned the difficult art of using the Eskimo kayak and became expert dog-drivers besides carrying out their several scientific duties.

Their record in little over a year included the survey of many hundreds of miles of coastline, two separate crossings to the West Coast and a perilous journey of boat and kayak for 600 miles (965 kilometres) round the coast, in which the leader supplied the party of three by hunting in the Eskimo manner.

For seven months they maintained a weather station 8,000 feet (2,440 metres) up on the ice cap, for five of which one of them, August Courtauld, endured, by force of circumstance, a solitary vigil in a tent under the snow and came through without scathe.

Two years later Watkins, then only 25 years old, was again in East Greenland with three of his former companions. Had he not been drowned by accident, he would have made a one-man crossing with a dog-sledge, to prove that it could be done.

In 1934 the Watkins system was put to the proof in the Antarctic, youth, economy and constant travel being once more the key to success. Another 14 men led by John Rymill, with four other Watkins men, set off from England in an old French fishing

schooner, bought for £3,000, with their amateur crew to sail to the Graham Land peninsula. There they spent two winters and three summers in the tricky navigation among the islands facing the Bellingshausen Sea, all at the trifling cost of £20,000.

From their second base, on the Debenham Islands, nine of the 14 made long journeys by dog-sledge and cleared up, by conscientious surveys, the major problems of the peninsula.

Twenty years later Fuchs was to follow the same pattern as far as possible in his vastly larger Trans-Antarctic Expedition. For his Crossing Party of twelve he selected men who could fulfil double, or even treble roles. In addition to having a speciality, each man had to learn to be a competent mechanic, and, if required, to act as deputy to at least one other of the scientists.

Throughout their journey of 2,000 miles (3,220 kilometres) the scientific work had priority over everything except safety, so that the men rarely got more than six hours sleep out of each 24.

This was exploration at its very best, not only finding what lay in the unknown but bringing back all the information about it that efficiency, forethought and determination could humanly achieve.

The amateur and volunteer element is another characteristic of expeditions from Britain. They are usually promoted by a few individuals and originate from private sources, though often supported by the Government later. The system permits an elasticity of purpose and a freedom from control which is often of value. On the other hand it carries some disadvantages. Britain, the great maritime nation, has not a single ice-breaker, so essential for modern polar work, and those belonging to smaller nations have to be chartered.

There has been, of late years, a tremendous increase in the number of small expeditions, emanating from and encouraged by universities in Britain, always scientific and sometimes for exploration, setting out to various parts of the world. They receive advice and some grants from learned societies, headed by the Royal Society and the Royal Geographical Society of London, supplemented on special subjects by such bodies as the Scott Polar Research Institute of Cambridge.

The spirit of adventure, one of the essentials of exploration, is being fostered as never before, and almost entirely on an amateur basis. It is a near approach to the ideal, when

> '*No one shall work for money and no one shall work for fame,*
> *But each for the joy of the working, and each in his separate star*
> *Shall draw the Thing as he sees It for the God of Things as They Are.*'

Britain's Contribution to Marine Science

BY DR. G. E. R. DEACON

It is often said that systematic study of the oceans started with the round-the-world voyage of Her Majesty's Ship *Challenger* in 1872–76, but its narrative pays tribute to earlier workers.

'The methods', it says, 'were crude, but they sometimes contained the germs of great ideas; the results arrived at were often erroneous, but they were steps in the right direction; and the researches were animated by the true scientific spirit, the spirit of observation and inquiry.'

But the 19th century was a great era for scientific exploration, not the least the exploration of the sea. Twelve of the 25 main voyages of exploration were British. William Scoresby made careful observations on water and ice conditions, plankton and whales in the Arctic Ocean. Parry and Sir John Ross also worked there. The voyage of the *Adventure* and the *Beagle* with Captain Fitzroy and Charles Darwin was made soon after and then 'the voyage of discovery and research in the Southern and Antarctic regions' by Sir James Clark Ross in the ships *Erebus* and *Terror*. This expedition was quite remarkable for the amount of astronomical, physical, botanical and zoological work as well as for its magnetic studies and exploration of the Antarctic.

At the same time Forbes was pioneering in marine zoology and building up an active school in Edinburgh. Wyville Thomson, who was scientific director of the round-the-world *Challenger* expedition (1872–76), followed him 20 years later.

The Royal Society had much to do with all these voyages; it made the appeals to the Government and set its committees to work on the plans. The *Challenger* expedition was on a really grand scale. When it returned, an office was set up to complete the reports, 50 large volumes, taking 20 years.

Lord Kelvin made outstanding contributions to marine science. He dealt with the effect of thermodynamic and geostrophic forces

on water movements as well as many practical inventions for navigation, ocean sounding, tide prediction and cable laying. Other prominent theoretical workers were Green, Airy, Young, Rayleigh, Stokes, Lamb and Reynolds. They seem to have had little influence on oceanographers such as Carpenter and Buchan, who had most to write about ocean circulation.

While rather slow progress was made with the ocean itself, much was done for navigation. Early in the century Rennell compiled a very thorough account of the currents of the Atlantic Ocean. In 1853, largely owing to efforts of Lieutenant Maury, of the United States of America's Navy, the principal maritime nations started to set up meteorological offices to collect systematic observations of winds and currents from all parts of the world.

All this growing experience and enthusiasm made Admiral Smyth write: 'The various branches of available science have been so steadily advancing among seamen of all nations that besides higher practice in mechanical navigation they possess a more accurate information respecting the phenomena of winds and oceanic currents than heretofore. Already the elements are nearly reduced to subjection by the union of science and practical seamanship so that sea passages are wonderfully shortened within memory.'

The problems today seem much more difficult. Voyages can no longer be shortened by two or three weeks, but the greatly increased volume of traffic makes it just as valuable to save a tide, to reduce loss and damage, and to lessen the cost of keeping ports open to ships of ever increasing size. These are too difficult to be solved by simple plotting and charting of observations. Science is the basis of engineering and the new problems need detailed study, using theoretical and practical techniques as advanced as those of all other industries.

Advances in the first 50 years of the present century seem to have been stimulated not so much by the needs of navigation as by fishery problems. Nations round seas in which fisheries were expanding so rapidly as to raise alarm about over-fishing joined to obtain reliable information that could be used to judge

what should be done. Each country needed the best information it could get.

In Britain it led to the growth of fisheries laboratories, marine biological associations and marine biological laboratories in the universities, and to a great wealth of biological study in British coastal waters and on arctic fishing grounds.

The *Discovery* Investigations, begun in 1924 to gain information about Antarctic whale populations, was a rather similar development. It started with an almost unknown ocean and had to look for all the background knowledge about water conditions, currents, fertility, plankton and especially the whale food, that would help and strengthen the interpretation of the whale observations.

The physical data and biological collections are even greater than those of the *Challenger* and will take longer to study because they are comprehensive and systematic enough to allow detailed study of the life-histories, spawning, growth and feeding habits of some of the plankton species.

Thirty volumes of reports published so far include generalisations about water movements and distribution of whales and plankton as well as the systematic and population studies.

Ice hazards to navigation started one expedition. In March 1913, nearly a year after the loss of the liner *Titanic*, a ship was sent out with very competent scientific observers, D. J. Matthews and G. I. Taylor, to judge whether steps could be taken to make the steamship routes across the Atlantic Ocean safer by establishing ice patrol vessels farther north.

The cost of the expedition was shared by shipowners and the United Kingdom Government. The findings, considered at a conference on the safety of life at sea held the same year, led to the establishment of an international ice patrol, now run by the United States of America Coast and Geodetic Survey. The theoretical and practical study of tides has given direct benefit to navigation.

In Britain the most prominent workers since Newton's time are Young, Whewell, Airy, Kelvin, Darwin, Hough, Goldsbrough, Proudman and Doodson. It was largely owing to Proudman that

the Tidal Institute was established in 1919 in the University of Liverpool. It was later combined with the Liverpool Observatory under the Mersey Dock and Harbour Board, directed since 1945 by Doodson, who had helped Proudman since the start. It has made very important contributions to the difficult task of explaining the complex systems of tides that exist in actual seas and oceans, and to the skilful methods of handling data needed to produce accurate tide predictions.

Much has been done and with facilities on a much more modest scale than those available to any other industry. Seafaring men do not really understand what science can do and scientists are not yet aware of the exciting problems in the sea. Thousands of ships suffer loss and damage every year, and enormous sums are spent every year to protect coasts and to maintain harbours, but there is not much demand for more science until some of the problems get out of hand in a war or in some other spectacular catastrophe. There was no really practical instrument for making continuous records of waves until 1944.

The first thing a scientist would do when studying a mixture of light, sound or radio waves would be to find its spectral composition, but for sea waves this was not done until 1945. It allowed Barber, Ursell, Darbyshire and Tucker at the Admiralty Research Laboratory, Teddington, Middlesex, to show that sea waves behave as though they originated in a large number of instantaneous point disturbances distributed over the storm area so that there is a continuous spectrum of wavelengths whose upper limit depends on the speed of the wind, and a wave pattern that is at any time the sum of a large number of component wave trains.

Since then another British scientist, Longuet-Higgins, has shown that the component wave trains behave as though they have random phase relationships. This allows the statistical distribution of such features as velocities, intervals between crests, slopes and length and direction of wave contours to be determined with remarkable accuracy. It is a fine continuation of the careful, though over-simplified, theoretical studies of earlier workers such as Stokes, Kelvin, Rayleigh and Lamb in this country and Cauchy, Poisson and others abroad.

Tucker has described a wave recorder that can be fitted in ships, and it has been used successfully for several years. It makes some compromise, accepting some limitations to achieve simplicity and robustness, but has not so far been improved on. Ship motions can be analysed in the same way as waves, and Cartwright and Rydill have shown that spectra of roll, pitch and heave are closely related to the wave spectra, so that the probabilities of different accelerations and stresses can be calculated. These advances, together with growing understanding of the sea surface, and the availability of electronic computers, have brought us to the threshold of developments that will have great influence on future ships.

Another interesting outcome of the spectrum-analysis approach to sea wave studies is a clear demonstration that interference patterns of sea waves can communicate sufficient energy to the sea floor to account for the microseismic oscillations of 3 to 10 seconds period that form a continuous background, greater in winter than in summer, on seismograph records.

The theory is well supported by observations, and as far as possible by experiment. It is not yet universally accepted, but with the help of further analysing and correlating equipment it can be used to obtain information about ocean storms and oncoming swell without going near the sea.

It may prove useful in countries that border on large oceans with poor meteorological cover. It has some interest in relation to the effect of deep explosions, and it may afford a means of studying geological features under oceans and land.

New advances are being made in the study of the transport of water by waves. They begin to add materially to our understanding of beach currents and of the factors likely to influence coastal erosion, transport of sediment and formation of submarine bars.

Much of this work had its beginning in war-time requirements. Since the war, it has been continued in the National Institute of Oceanography, founded in 1949 to supplement the work of the fishery and marine laboratories by detailed studies of the physics of the oceans. It also studies the plant and animal life outside the coastal region and main fishing grounds.

The Institute is controlled by the National Oceanographic Council, which was granted a Royal Charter, and operates with the aid of Government grants. The emphasis of its programme is on long-term research.

The nucleus of physicists came from the Admiralty Research Laboratory, and of biologists from the *Discovery* Investigations. Useful progress has been made and new tasks taken on, such as study of the sea floor and of the active movements of water and sediment that sometimes occur even at very great depths. There are many remarkable gaps in our knowledge of the sea. The specific heat of sea-water had not been measured since 1889, and a new series of measurements using modern techniques has proved well worth while.

There are interesting and important chemical problems. By 1819 a London doctor, Marcet, went so far as to say that the principal constituents of the dissolved salt are present in the same proportions to each other all over the world. He had only 14 samples, but much more extensive work by Forchhammer in Denmark and Dittmar, who analysed *Challenger* samples in Glasgow, did not prove him wrong.

The small differences that can now be detected, especially in radioactive substances which do not last long enough to be mixed with the ordinary constituents to the same degree all over the world, provide interesting problems. Atkins and Harvey, of the Plymouth laboratory, roused interest in the study of nutrient cycles in the sea, and much more, including the occurrence and effect of trace elements, has been done.

The joint theoretical and practical study of ocean circulation, so long in need of special attention, seems to be making good progress. The quantitative study began with calculations based on pressure distributions in the ocean, using a method similar to that used to deduce wind speeds from the spacing of isobars in weather maps. But it gives relative figures, and the final interpretation depends on knowing the speed at any one depth.

The earliest device was to assume that the water at the bottom of the sea was motionless. Later it was proved more reasonable to assume that there was least horizontal motion at the depth where

the isobaric surfaces at neighbouring observation points were most nearly parallel. There was urgent need of actual measurements, and those made from ships anchored in deep water were not reliable enough.

The National Institute of Oceanography tried to plot the descent of slowly sinking acoustic transmitters in much the same way as meteorologists follow ascending balloons using acoustic apparatus instead of theodolites or radar. It proved too difficult, but Dr. Swallow devised a much more practical method. He mounted the transmitter on a float which is less compressible than sea-water. If such a float is made slightly heavier than the same volume of sea-water at the surface, the density difference decreases as the float sinks until, at some predetermined depth where the float has the same density as the water, it sinks no farther but drifts horizontally with the current. The acoustic transmitter can be followed by a surface ship fitted with hydrophones.

More and more of this sort of work is being done and strong and often variable subsurface and deep currents are being found and studied. Most of it is being done by British and American scientists in close co-operation. None of their theories is completely successful, but there is often sufficient agreement with measurements to make the work very exciting.

Research is particularly important because the great size and variability of the oceans will make our few observations ineffective until we have as much guidance as possible from physical and biological principles. But there is still much exploratory work to do and British ships made useful contributions during the recent great joint effort of the International Geophysical Year.

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the Modern World series.
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Others will follow.